Technical Report: NAVTRADEVCEN 1297-1

STUDY OF WAKE GENERATING SYSTEM FOR AN ASW TRAINING DEVICE

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ABSTRACT

When used as an acoustic submarine simulator, Training Device 21B12 does not generate a realistic wake. Since the characteristics of a submarine wake must be recognized by ASW operators, the development of an artifical wake generator was undertaken.

Various methods were investigated. The use of sodium borohydride (in an acid environment) as an active hydrogen generating material, which in the form of small bubbles simulates the wake, was selected as the most suitable method because of its efficiency, safety, and weight. An experimental model was constructed and tested at the U.S. Underwater Sound Laboratory and at sea with the assistance of the U.S.S. Gyatt. The artificially generated wake appeared on the sonar equipment very much like a real wake.

Further tests should be made to establish the geometry of the artificial wake. These tests should be conducted at a well-equipped naval facility, such as Key West.

FOREWORD

Wake trails are an important element in the tracking and classification of submarines as sonar equipments are improved. The recognition of these trails, determination of target aspects, detection of false target reflections, and real target penetration through the wake are difficult areas of training for sonar operators. Because of this, a project was pursued by the ASW Systems Trainers Branch, U.S. Naval Training Device Center, Port Washington, New York to obtain a means for artificially creating a wake trail. This would be used in conjunction with a free running underwater vehicle, which because of its small size does not create a wake, but can simulate most other submarine characteristics.

This project was conducted under contract to TRG Incorporated, Melville, New York, and an experimental model developed based on a chemical generation of hydrogen gas in a 10 x 42 inch tank open to provide access for seawater and egress of hydrogen gas. The active material is sodium borohydride in the presence of a dilute solution of sulfuric acid.

Measurements were made with the generator under controlled conditions in a test lake where acoustic transmission loss and reflectivity values were determined. After it was determined that the wake strength corresponded to that of a submerged submarine, tests were run with operational shipboard sonars. All results have proven acceptable resulting in a new simulation approach.

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INTRODUCTION

The wake trial generated by a moving object in water, such as a surface vessel or a submarine, is detectable by means of sonar equipment. The ability to detect and recognize the wake, which persists for a considerable time after the generating vessel has moved to another location, forms an important part of the training of sonar personnel. The density, the strength, the length and the transparency are important wake characteristics that can be recognized only after many demonstrations and instructions.

Training device 21B12 simulates the acoustical characteristics of a submarine and is used in most ASW training programs. However, this relatively small torpedo-shaped device (13 ft, long by 1 ft in diameter) does not generate a realistic wake.

The possibility of generating an artificial wake by means of chemical, electrolytic, galvanic, or other methods was investigated under this program. The chemical method using sodium borohydride as an active hydrogen-generating ingredient was selected. An experimental vehicle was designed and various tests were made at the U.S. Naval Underwater Sound Laboratory and at sea. The last and most conclusive test, made with the aid of the U.S.S. Gyatt, proved that the artificially generated wake showed the same characteristics on the sonar display as the wake of the submarine.

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SECTION II

STATEMENT OF THE PROBLEM

A. THE CHARACTERISTICS OF A SUMARINE WAKE

The wake of a moving vessel can usually be observed as a turbulent disturbance of the water surface with a foamy appearance. The movements of the vessel, though the vessel itself might be out of visual range, can be recognized, since the wake persists over a considerable length of time. This clearly indicates the importance of wake recognition in tactical naval operation.

In addition to the visual effects, the wake presents an acoustical discontinuity in the seawater, which can be detected by sonar equipment. The acoustical wake is of prime importance in ASW operations where the wake of a submerged submarine cannot be detected by visual means.

In the ASW training program, device 21B12 is used as an acoustical submarine simulator. This torpedo-shaped device (13 ft long by 1 ft in diameter which is shown in Figure 1) simulates all acoustical properties of a submarine but, because of its small size it does not generate a wake. The development of an artificial wake generator was undertaken under this program with the objective that such a generator will be incorporated in present or future training devices. A number of restrictions, however, must be considered: (1) the total device must be zero-buoyant, (2) its size must be small enough to make incorporation with the 21B12 feasible, (3) it must be safe to handle, (4) it must be reusable, and (5) the active wake-generating material must be relatively inexpensive.

During the first two months of the program, a study of the acoustical properties of wakes was made. Literature describing theoretical analysis and experimental measurements on the acoustical properties of wakes was supplied by the U.S. Naval Training Device Center. In addition, a demonstration on board the U.S.S. Sierra was arranged by NTDC in October 1962. During this demonstration, the recorded tactical maneuver of a submarine was displayed on the sonar equipment. The submarine disappeared in its own wake and was lost on the sonar indicator. Although the demonstration did not provide any information on the geometry of the wake, because of the limited resolution of the sonar, the impottance of the acoustical properties of the wake was obvious. For example, the trained sonar operator could distinguish between the sharp reflection of the hull of the submarine and the mushy reflection of the wake. This can easily be explained by the difference between the solid boundary of the submarine

FIGURE 1. ASW SUBMARINE TARGET, DEVICE 21B12, TYPE I

hull and the gradually changing boundary of a wake. Furthermore, relative motions of the submarine and the wake, with respect to the sonar ship, could be detected by doppler shift effects.

Little information is available about the geometry and properties of submerged submarine wakes. Since the surface wake and the submarine wake are mainly caused by the propeller cavitation effects, many of the considerations and information on the surface wake apply to the submerged wake. However, a number of striking differences must be considered: (1) the decrease in wake strength when the submarine changes to a greater depth at a constant speed, and (2) the upward motion of the submarine wake as a function of time.

In reference 1 the important factors, such as the bubble resonant frequency and the concentration of air relative to seawater in wakes of different strengths, are described in detail. The characteristics of a submerged submarine wake are summarized below.

The wake consists of a large concentration of gas bubbles, resulting from the diffusion of gas, normally dissolved in the seawater, into the vacuum cavity created in areas of negative pressure near the propeller blades and the vessel's hull. When these cavities collapes, the diffused air is compressed and remains behind as a small bubble. This bubble will dissolve slowly back into the seawater. Since the specific weight of the bubble is much smaller than that of seawater, it will move in an upward direction. The relative ratio of gas (air) and water in a strong wake is in the order of 1 part in 10^6 and, for a weak wake, 1 part in 10^8.

The size of a submarine wake is estimated to be about three times the width of the submarine, which for most practical purposes is assumed to be 20 feet. From this we can compute the total amount of air contained in a wake generated by a submarine traveling at a speed of 10 knots for a period of 2 hours. The total amount is about 10,000 liters. The bubble size is a function of the depth, the cavitation source, and other known factors. However, the average radius of bubbles close to the surface is between 0.01 and 0.1 cm. The acoustical discontinuity of a wake is directly related to the bubble resonant frequency, which, in turn, is a function of the bubble size. The resonant frequency of bubbles containing different gases, such as oxygen, air, or hydrogen does not differ more than a few percent. The resonant frequency as a function of the bubble size is shown in Figure 2.

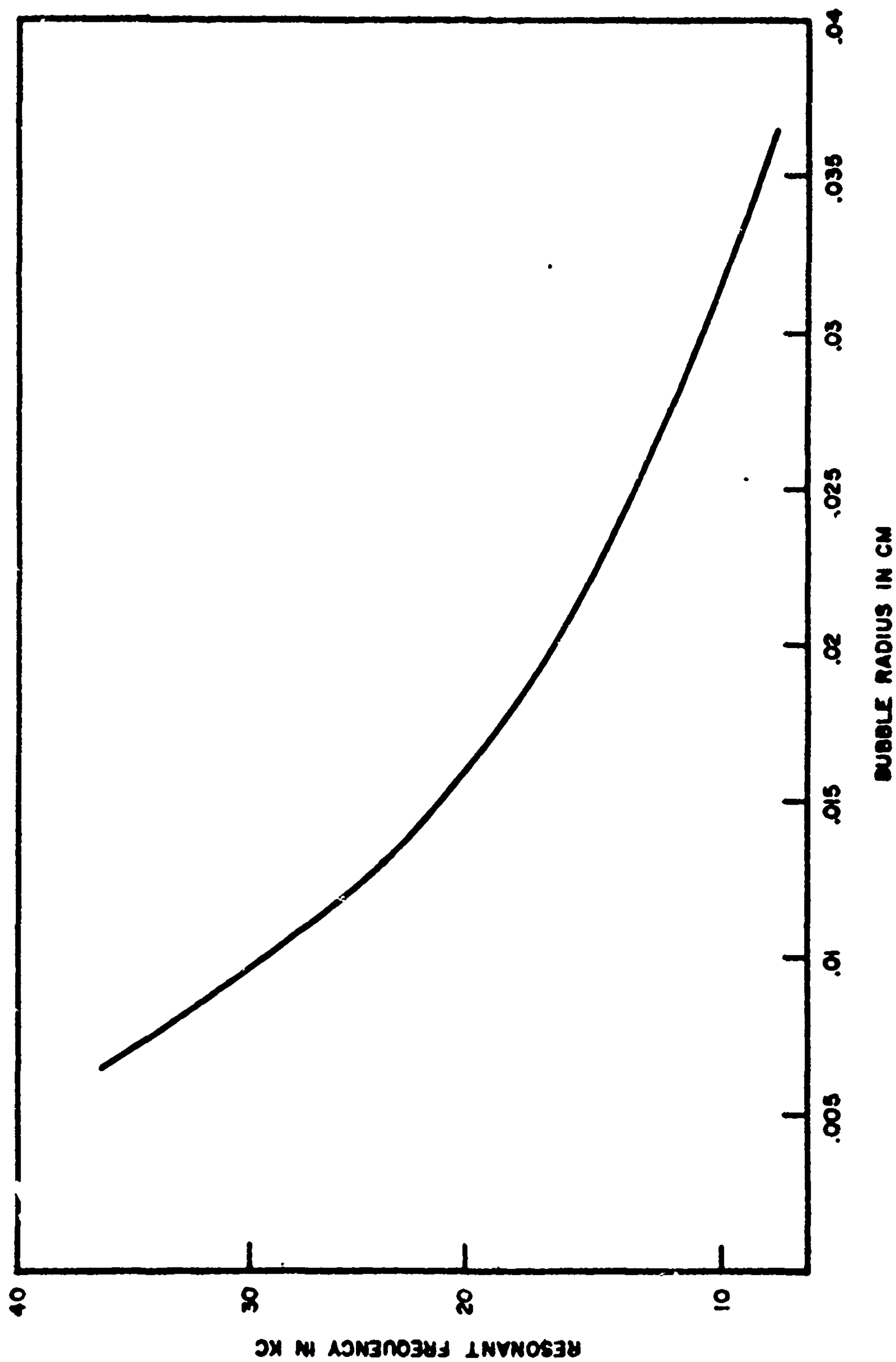

Figure 2. Acoustical Resonance Frequency versus Bubble Radius

B. METHODS OF GENERATING A WAKE

Other materials than gases can be considered to simulate the acoustical properties of a wake. However, the required wake geometry would demand the storage of a large volume of solids (liquid cannot be used, since it has about the same density as the wake). Furthermore, the releasing of solids in a continuous flow into the water would require a rather complicated mechanism.

The Coast Guard has performed experiments with metallic chemicals that, when released into the water, generated a large amount of hydrogen bubbles that proved to be an effective sonar target generator. The chemicals used were lithium hydride, and the test is described in reference 2. However, in these experiments no effort was made to control the reaction, and the use of lithium presented a serious problem as a result of its instability.

An electrolytic method, where gas is liberated by the flow of electrical current through the seawater, is impractical because of the large amount of stored energy required to generate 10,000 liters of gas. A galvanic generator, using magnesium as one of the elements of a fuel cell, will liberate hydrogen when a current is allowed to flow. Space/Avionics, Inc. markets a 0.2-kw fuel cell that operates for a period of 20 hours and generates about 2000 liters of hydrogen. The unit uses 5 pounds of magnesium and weighs 25 pounds.

For 10,000 liters of hydrogen, the total weight of such a unit would be 125 pounds. In addition, the reaction of such a quantity of hydrogen cannot be completed in the relatively short time of 2 hours.

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SECTION III

THE CHEMICAL METHOD OF GENERATING AN ARTIFICIAL WAKE

A. TYPES OF CHEMICALS SUITABLE FOR GENERATING AN ARTIFICIAL WAKE.

Hydrogen is the most practical gas to form the large number of bubbles required in an artificial wake, since two volumes of hydrogen and only one volume of oxygen are available from the seawater for a given amount of electron transfer (or displacement type of chemical reaction).

Water is such a stable chemical that active materials must be used to release the hydrogen. Therefore, an active metal such as magnesium (coupled with acid or some inactive metal) would be required if metals are considered. The generating capacity of magnesium is one hydrogen molecule (H_2) for each magnesium atom (Mg).

On the other hand, metal hydrides are salt-like compounds that provide one additional hydrogen atom for every hydrogen atom obtainable from water. Thus, two hydrogen (H_2) molecules are available by reaction of one molecule of magnesium hydride (MgH_2) with water (H_2O). In addition to magnesium, many other metals are available for the intended purpose. In the following section these materials are tabulated with respect to their efficiency.

B. AMOUNTS OF MATERIALS REQUIRED

The total calculated amount of gas required to generate a strong artificial wake during a 2-hour period is equal to 10,000 liters. The required amounts of the various chemicals that can be used to generate this volume of hydrogen, under standard conditions, are tabulated below.

TABLE I.

REQUIRED AMOUNT OF VARIOUS CHEMICALS FOR 10,000 LITERS HYDROGEN

MATERIAL	FORMULA	WEIGHT (KILOGRAMS)	WEIGHT (POUNDS)
Magnesium	Mg	10.8	24
Calcium Hydride	CaH_2	9.4	21
Aluminum	Al	8	17.6
Magnesium Hydride	MgH_2	5.9	13
Lithium Aluminum Hydride	$LiAlH_4$	4.2	9.25
Sodium borohydride	$NaBH_4$	4.2	9.25
Lithium Hydride	LiH	3.6	8
Lithium borohydride	$LiBH_4$	2.45	5.4

C. EVALUATION OF MATERIALS

Table I shows that the metal hydrides are leading in hydrogen-generating capacity per unit weight. The best material is lithium borohydride. However, this material is not readily available in the desired dry powder form and would be too expensive for this program. Lithium hydride is available but, because of its instability, it is dangerous to use. In addition, its shelf life is short and the reaction is very short and violent.

The material selected for this program is sodium borohydride. This chemical has a number of advantages: (1) it is readily available in powder form at a moderate price, (2) it is stable in slightly alkaline water, such as seawater, (3) it can easily be packaged in the form of cakes or cartridges, (4) its solubility in water is high and, (5) it is safe to handle.

Since sodium borohydride does not react with seawater, because of the alkaline condition, an acid is required to create the proper conditions for the chemical reaction. This acid can be released in the water in the vicinity of the area where the sodium borohydride is released. Although various acids can be used, ammonium bisulfate (NH_4HSO_4) and sodium-bisulfate ($NaHSO_4$) in cast form, are the most practical chemicals for this program. The casts are made by melting the chemicals. Since the melting temperature of ammonium bisulfate is only 150°C as compared with 180°C for sodium bisulfate, the first chemical was selected for this program. To provide a convenient and safe method of handling the two selected chemicals (sodium borohydride and sodium bisulfate), the use of two storage tanks, each filled with a chemical solution, was investigated. The pressurized tanks were connected by a tubing and valve arrangement to a common nozzle where the reaction takes place. However, this approach, described in some detail in the preliminary report published under this contract (reference 3), proved to be impractical because of overall size and weight considerations.

The use of solid castings of both chemicals was then investigated. Sodium borohydride in saturated solution mixed with powdered anhydrous sodium borohydride in a very dilute sodium hydroxide when poured in a mold, will solidify to a cast in the desired form. A 3.3-pound cake measuring 7 by 2 inches was selected as the most suitable form. The cake, consisting of 2/3 by weight of sodium borohydride and 1/3 by weight of water, has a density about equal to that of seawater. The acid, (sodium bisulfate) when melted at a temperature of 100°K, can easily be cast in the form of a cake measuring 4 by 2 inches. The density of the acid cakes is about 1.5 times that of seawater.

The two materials are only toxic when contacted by the moist skin. A mild skin irritation could result when the hands are not washed shortly after contact. Splashing into the eyes is impossible with solid cartridges. There is no discernible absorption of water by either of the two chemicals, when they are wrapped in a suitable plastic for storage.

D. THE CONSTRUCTION OF THE WAKE GENERATOR

Figure 3 shows the construction of the artificial wake generator. The aluminum cylinder, which has a diameter of 10 inches and a length of 3 feet, houses the active chemicals. The diameter is compatible with the diameter of training device 21B12. The sodium borohydride, which is cast in the form of a cake is stored in the cylindrical chamber with perforated outside walls. A total of three cakes is used. The perforations allow the seawater, which flows through the tubing, to dissolve the chemical and carry it past the perforated chamber containing five cakes of ammonium bisulfate. The sodium bisulfate also dissolves and the chemical reaction, resulting from the presence of both chemicals in seawater, generates the desired hydrogen bubbles. The reaction continues after the chemicals have left the generator, since it will take some time before the concentration is reduced to a value too low for a meaningful reaction.

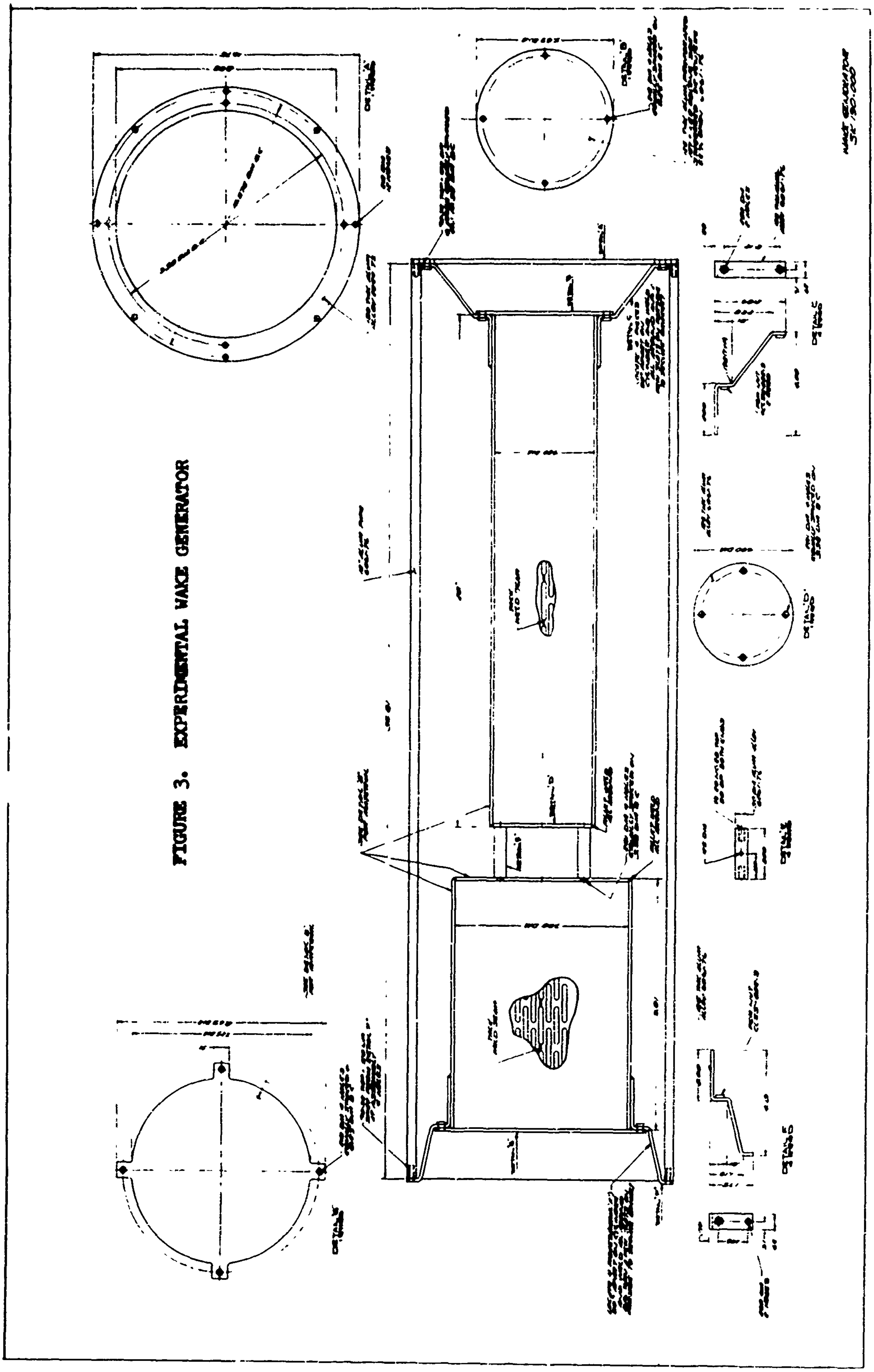

FIGURE 3. EXPERIMENTAL WAKE GENERATOR

The generator was provided with a shroud at the rear to stabilize it during towing, and simple eyebolts were used to connect the towing cable. The wake strength is a function of the rate at which the chemicals are dissolved. Therefore, a second perforated tubing was placed around each chamber which, when rotated, controlled the net opening through which the seawater dissolved the chemicals. The total weight of the generator is 55 pounds, of which 15 pounds represents the chemicals.

Two generators were constructed during this program. The first unit, made of stainless steel, contained an air chamber to provide zero buoyancy when necessary, and the second unit was made of aluminum and had a negative buoyancy. The differences between the two generators are small.

E. TESTS AT THE U.S. NAVY UNDERWATER SOUND LABORATORY

The first experimental model was prepared for testing at the U.S. Navy Underwater Sound Laboratory, New London, Connecticut on 28 August 1963. Two 80-foot vessels were used, one of which was equipped with a transducer and hydrophone, and the other was used for towing the generator.

An explanation follows of why these tests were made completely inconclusive.

The area selected by the U.S. Underwater Sound Laboratory was located between Fishers Island and Long Island off the Connecticut coast. However, upon arrival, it was discovered that extensive fishing was performed in that area so that another location was selected. Since a depth of 200 feet was required to perform the test, the only area available was in "the Race" a small channel where the tide currents associated with the Long Island Sound pass through. After the anchor was dropped and the transducer and the hydrophone was let into the water, it was learned that the strong tide current pulled the sonar equipment under a 45° angle. An attempt was made to record the reflection of the generator, which was towed at a speed of 5 knots at a distance of about 150 feet, from the sonar equipment and at a depth of 50 feet. No reflections were visiable. During the next few hours, while waiting until the tide current would reduce, the transducer support cable came loose and the seal of the single cable, which now supported the transducer, developed a leak. Although repairs were made, this resulted in a reduction of the available transducer power by a factor of ten. Furthermore, both the transducer and the hydrophone were of the omnidirectional design, resulting in a rather low system sensitivity. However, a few more test runs were made without any sign of reflection. It should be noted that not only did the artificial wake not show on the sonar equipment, but the towing vessel was also never observed on the sonar recorder. In order to complete this dreadful day in style, the towing line was cut by a sharp edge of the wake generator while it was pulled back on board. The generator fell back into the water and is presently resting on the bottom of Long Island Sound.

It was mutually agreed that the next test would be performed at the Dodge Pond facilities of the Underwater Sound Laboratory, where conditions are well controlled and accurate measurements can be performed.

The second experimental wake generator, constructed to replace the lost unit, was prepared for testing at the Dodge Pond facilities. On 5 December 1963, a series of test runs were made. The generator was towed by means of a small boat at a speed of about 3 knots. A phased-array transducer arrangement was installed and two hydrophones were used to record the transmission loss and the reflection of the wake. The test indicated that the artificial wake generated attenuated the sound picked up by the hydrophone behind the wake by 15 db. The reflections of the wake were also clearly visible.

The results of these tests justified the next and most important test under this program--that is, the environmental test at open sea. The Requirements Department of the Naval Training Device Center arranged the commitment of the U.S.S. Gyatt, stationed at Norfolk, Virginia, for this purpose.

F. TEST ON BOARD THE U.S.S. GYATT

On 18 March 1964, a series of tests were performed on board the U.S.S. Gyatt. A short test made the day before, using the ship's whale boat to tow the generator, was unsuccessful because of communication difficulties between the sonar operators and the whale boat, resulting in a number of runs so close to the Gyatt that the sonar could not record the return signal. The sea state was rapidly increasing and further tests were abandoned for that day.

The following day the sea state increased to four and testing by means of the whale boat was, therefore, impossible. It was decided that the wake generator would be towed by the Gyatt while the Gyatt would make a continuous turn with a diameter of about 1500 feet. Three such runs were made with slightly varying dissolving rates. All three runs showed a clear wake trail which, according to the ship's sonar operators, was identical with a submarine wake.

SECTION IV

RESULTS

A. RESULTS OBTAINED AT THE U.S. NAVY UNDERWATER SOUND LABORATORY

On 5 December 1963, the second experimental wake generator was tested at the Dodge Pond facilities of the U.S. Naval Underwater Sound Laboratory. The fresh water pond is equipped with a floating sound laboratory with facilities to lower transducers and hydrophones into the water. At a distance of 140 feet from the transducer a 10 foot line hydrophone was lowered from a target float. A second hydrophone was lowered at a location 35 feet to the right of the transducer. The arrangement is shown in Figure 1 of Appendix A. The transmitting frequency was 5 kc with a pulse length of 2 milliseconds and a repetition rate of 1 pulse per second. The wake generator was towed between the transducer and the 10 foot line hydrophone at a distance of about 75 feet from the transducer. A total of thirteen active runs and two inactive runs (without generating materials), was made.

The generator was towed at a speed of 4 knots at an average depth of 25 feet. Table I of Appendix A shows that the average reflection loss decreased from the reference value of 26 db (measured with an empty generator) to 12 db with 7.6 db as the lowest and 19 db as the highest value. The transmission loss (shown in Figures 7 through 11 of Appendix A) shows that the maximum value of 24 db lasted for only a few seconds during run No. 6. It is interesting to note that the average value of the transmission loss slowly increased when more runs were made, indicating that small bubbles, which do not rise to the surface as fast as the large ones, accumulated. Run No. 13, which shows a constant 13-db insertion loss, was made with an almost empty generator and small bubbles only were generated. This was also visually observed by allowing the generator to operate close to the surface.

Although it is impossible to determine the wake geometry from these tests, the results clearly indicated that appreciable reflections and transmission losses were obtained. The complete results, as reported by the Underwater Sound Laboratory, are given in Appendix A.

B. RESULTS OBTAINED ON BOARD THE U.S.S. GYATT

On 17 and 18 March 1964, tests were performed on board the U.S.S. Gyatt at open sea. The generator was prepared and lowered in the whale boat. With the U.S.S. Gyatt anchored in a fixed position, the whale boat towed the generator in two runs in a course parallel to the Gyatt at a distance of about 100 feet. However, when no reflections were observed, it was realized that the minimum range of the ship's sonar equipment was 300 feet. The sea state was rapidly deteriorating and the small whale boat was ordered back to the ship.

The following day the sea state, which increased to 4, did not allow the whale boat to be used as a towing vessel. The generator was towed from the U.S.S. Gyatt while running a circular course with a diameter of about 1500 feet at a speed of 6 to 8 knots. The towing line length of about 1000 feet caused the generator to be pulled at a depth of 120 feet, with an uncertainty of ±50 feet. The sonar operating frequency was 10 kc with pulse lengths of 6 and 30 milliseconds.

A total of three test runs was made, and each run lasted about 20 minutes. During the first test run, the generator was loaded at 2/3 of its full capacity; the opening controlling the rate at which the sodium borohydride dissolved was set at its maximum. The wake observed on the sonar equipment is shown in Figure 4, which is a sketch copied from the sonar display. Photographic equipment was unfortunately not available on board the Gyatt.

The second test run was made with the generator fully loaded and the dissolving rate openings at half. This test run presented the most realistic wake. Personnel of the Naval Training Device Center and TRG personnel were unable to view the sonar display because of serious discomforts resulting from the heavy sea state. Since the U.S.S. Gyatt described a circular course at low speed, the roll angle exceeded ±30°. In addition, the high wind carried showers of seawater over the upper deck, where the wake generator was being loaded. However, the handling of these chemicals, under rather adverse conditions, did not create any difficulties or hazardous conditions.

The third run was made with a fully loaded generator with the opening at maximum. The appearance of this wake was identical with that of the first wake except for a lightly lower strength.

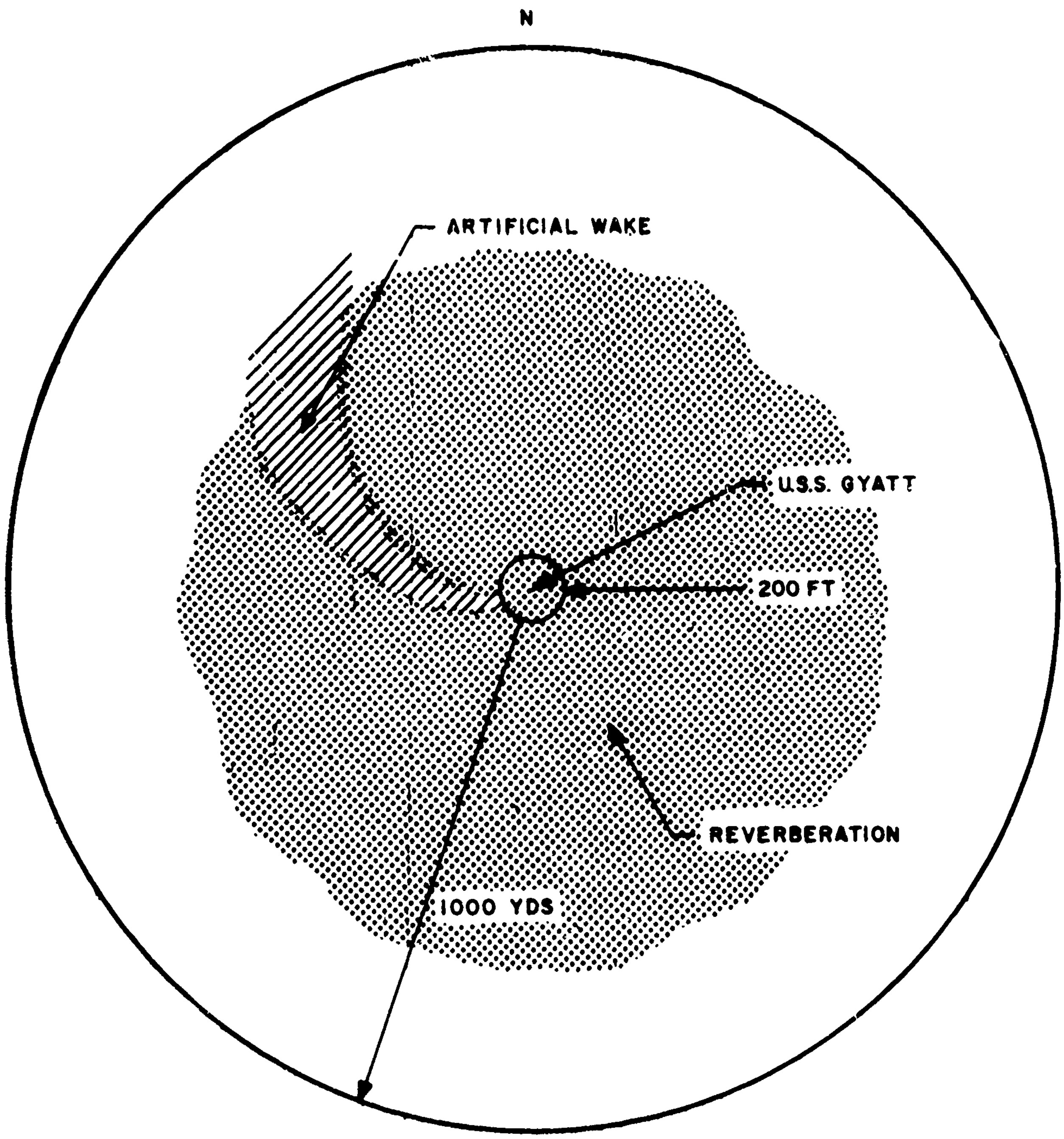

Figure 4. Sonar Return of Wake

SECTION V

DISCUSSION

Of the three tests made, (two at the Underwater Sound Laboratory and one on board the U.S.S. Gyatt) only the second and the third were conclusive. The failure of the first test was due to a combination of unfortunate circumstances; however, the experience gained contributed to the success of the following tests.

The second test indicated that a definite attenuation and reflection of the generator was obtained. The variations in intensity of both the reflection coefficient and the attenuation of the wake are due to the difficulty of guiding the generator while towing it from an 8-foot rowboat in the presence of the anchor line of the floating laboratory and the target float. No information on the actual geometry of the wake could be obtained because of the depth at which the generator was towed (25 feet). A very interesting observation is that the average transmission loss increased with the number of runs made, indicating an accumulation of small bubbles, which do not rise to the surface as fast as the larger ones. The average bubble size could not be determined by dissonant absorption method, since only one frequency was available for this test. However, the results indicated that a full-scale test, at open sea, would be justified.

The third test was made at open sea on board the U.S.S. Gyatt. Three test runs were successfully completed. A very realistic wake was observed, especially during the second run when the generator was fully loaded with the dissolving rate at half. The second and third runs showed that the average generating time was 20 minutes. Since the generator contained about 6 pounds of sodium borohydride, which under ideal conditions would generate 7000 liters of hydrogen, the generated wake should be very strong. In addition, it must be realized that 100 percent efficiency will never be obtained. Laboratory tests indicate that 30 to 50% percent efficiency should be considered satisfactory. The geometry of the artificial wake, with respect to width and height, could not be observed because of the limited resolution of the Gyatt's sonar equipment. However, the wake depth was estimated at 120 feet and, according to experienced sonar operators, could not be mistaken for a surface wake.

SECTION VI.

CONCLUSION

The artificial wake generator developed under this program, which is capable of generating an artificial wake that is very much identical with a real submarine wake, has been successfully tested. The chemicals used are relatively inexpensive, readily available, safe to handle, and can be stored indefinitely. The design principle can be included in the ASW training device 21B12 with only minor modifications.

The strength of the generated wake can be regulated by controlling the amount of water flowing over the surface of the chemicals. These controls can be inccrporated in the control system of Training Device 21B12.

SECTION VII

RECOMMENDATIONS

It is recommended that some further experiments be performed at a suitable naval facility such as Key West. The following factors should be considered in determining the location: (1) the facility to observe the wake visually as well as acoustically, (2) the facility to tow or otherwise propel the generator in an exact course, and (3) when the generator is included in device 21B12, for example in the form of a new section located between the two front sections of the device, all facilities to service device 21B12 must be available.

A number of alternatives with respect to dissolving the chemicals should be investigated before the generator is included in device 21B12. For example, when the sodium borohydride is released near the front of device 21B12, it is probably advantageous to release the acid sodium bisulfate at regular intervals along the surface of the device to ensure the continuous acid environment required to generate the small hydrogen bubbles.

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APPENDIX A

U.S. NAVY UNDERWATER SOUND LABORATORY
FORT TRUMBULL, NEW LONDON, CONNECTICUT

ACOUSTIC MEASUREMENTS ON TRG ARTIFICIAL SUBMARINE WAKE GENERATOR

by

Robert O. Kindl

USL Technical Memorandum No. 954-4-64

22 January 1964

U. S. NAVY UNDERWATER SOUND LABORATORY
FORT TRUMBULL, NEW LONDON, CONNECTICUT

ACOUSTIC MEASUREMENTS ON TRG ARTIFICIAL SUBMARINE WAKE GENERATOR

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INTRODUCTION

Acoustic measurements were made on the wake generated by the TRG artificial submarine wake generator to determine its acoustic transmission loss and reflectivity.

The measurements were conducted at the Dodge Pond Field Station which is located on a fresh-water pond.

DESCRIPTION

The generator is cylindrical in shape, 10 inches in diameter and 36-42 inches in length. Gas bubbles are generated by the reaction of sodium borohydride and sodium bisulfate as the generator is towed through the water.

TEST SETUP

Both the reflectivity and transmission loss through the wake were measured using 2 ms 5 KC pulses at a repetition rate of 1 pulse per second. This short pulse length was necessary to separate the main signal and surface reflections. Fig 1 shows the transmitting and receiving systems used for these measurements.

The test geometry is shown in Fig 2. Water depth was approximately 45 feet with a high loss mud bottom. The water temperature was 45°F and isothermal from the surface to the bottom within 2°.

The source projector had a beam width of 22° at the 3 db down points. The directivity pattern of the source is shown in Fig 3.

Line hydrophones were used for receiving the signals to distinguish against surface reflections. Both hydrophones have an omnidirectional receiving response in the horizontal plane.

The wake generator was towed at a speed of approximately 4 knots.

REFLECTIVITY MEASUREMENTS

Since accurate physical dimensions of the wake were not known, the wake strength could not be calculated. (See reference (a).) Therefore, the observed reflection loss was measured by comparing the received echo level at the 2' line hydrophone with that predicted by assuming only standard spreading loss; 20 log R, where R is the distance in yards from the source to the wake and back to the receiving hydrophone. The value of R was computed from the measured travel time using a nominal sound velocity of 4,700 feet per second.

Table I gives the measured reflection loss and distance from the source to the wake for each run.

The reflection loss is given by $20 \log \frac{L\ w_i}{L\ w_r} = S - E - 2\ H$, where $L\ w_i$ is the incident sound pressure level at the wake in db//1µb; 1 wr is the reflected sound pressure level at the wake in db//1µb; S is the source level in db//1µb at 1 yard; E is the echo level at the receiving hydrophone in db//1µb; and 2 H is the total transmission loss in db, here assumed to be 20 log R, where R is in yards.

Figs 4, 5, and 6 show typical echo returns.

Two runs were made using only the empty generator. The measured reflection loss was 25.8 and 29.3 db respectively.

TRANSMISSION LOSS MEASUREMENTS

Transmission loss through the wake was calculated by comparing the signal level at the 10' line hydrophone, see Fig 2, as the wake generator was towed, with a reference level taken before the tests had started. Figs 7-11 show the observed loss vs time for each run.

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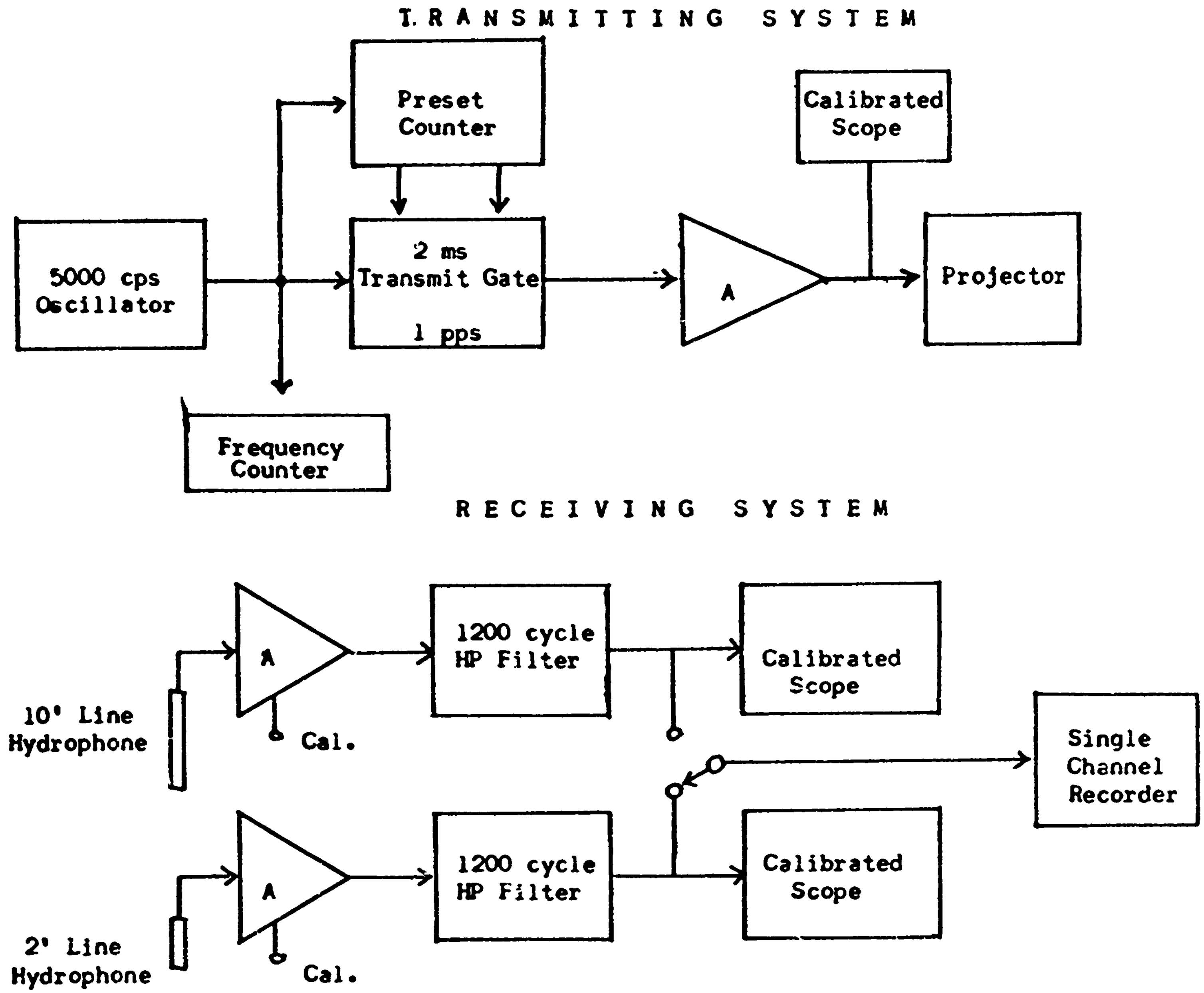
ROBERT O. KINDL

Reference

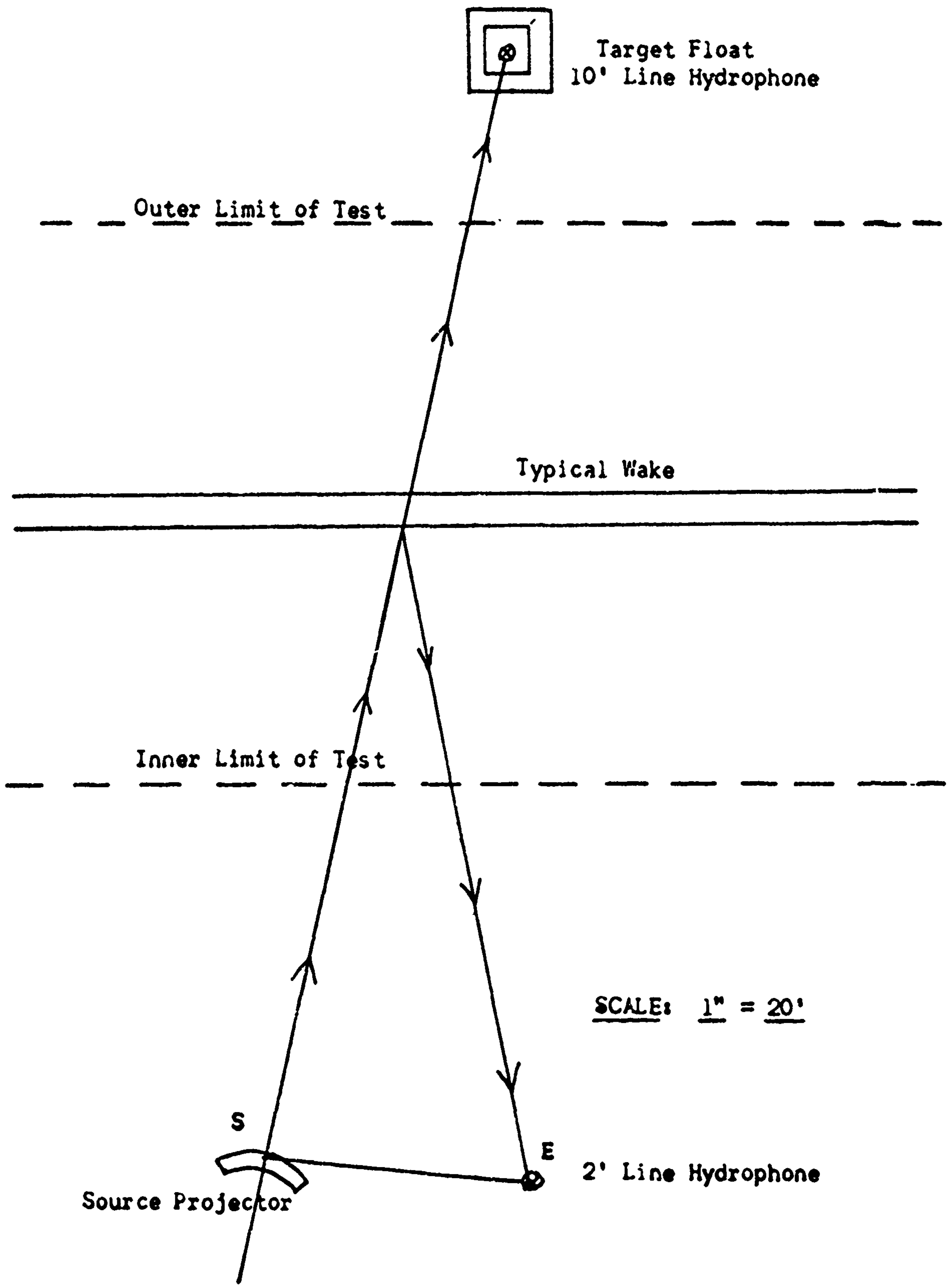
(a) NAVORD Report 5891, "Submarine Echoes and Wakes, Summary and Evaluation of the Literature," dtd 20 May 1958, pp 52-54, (C).

TABLE I

Run No.	Distance From Source to Wake in yds	Reflection Loss 20 log $\frac{Iwi}{Iwr}$
1	No Data	---
2	34	7.6
3	25	11.1
4	21	15.7
5	20	10.5
6	18	19.0
7	25	13.3
8	21	17.6
9	21	12.0
10	24	12.4
11	28	8.9
12	16	12.2
13	16	12.2

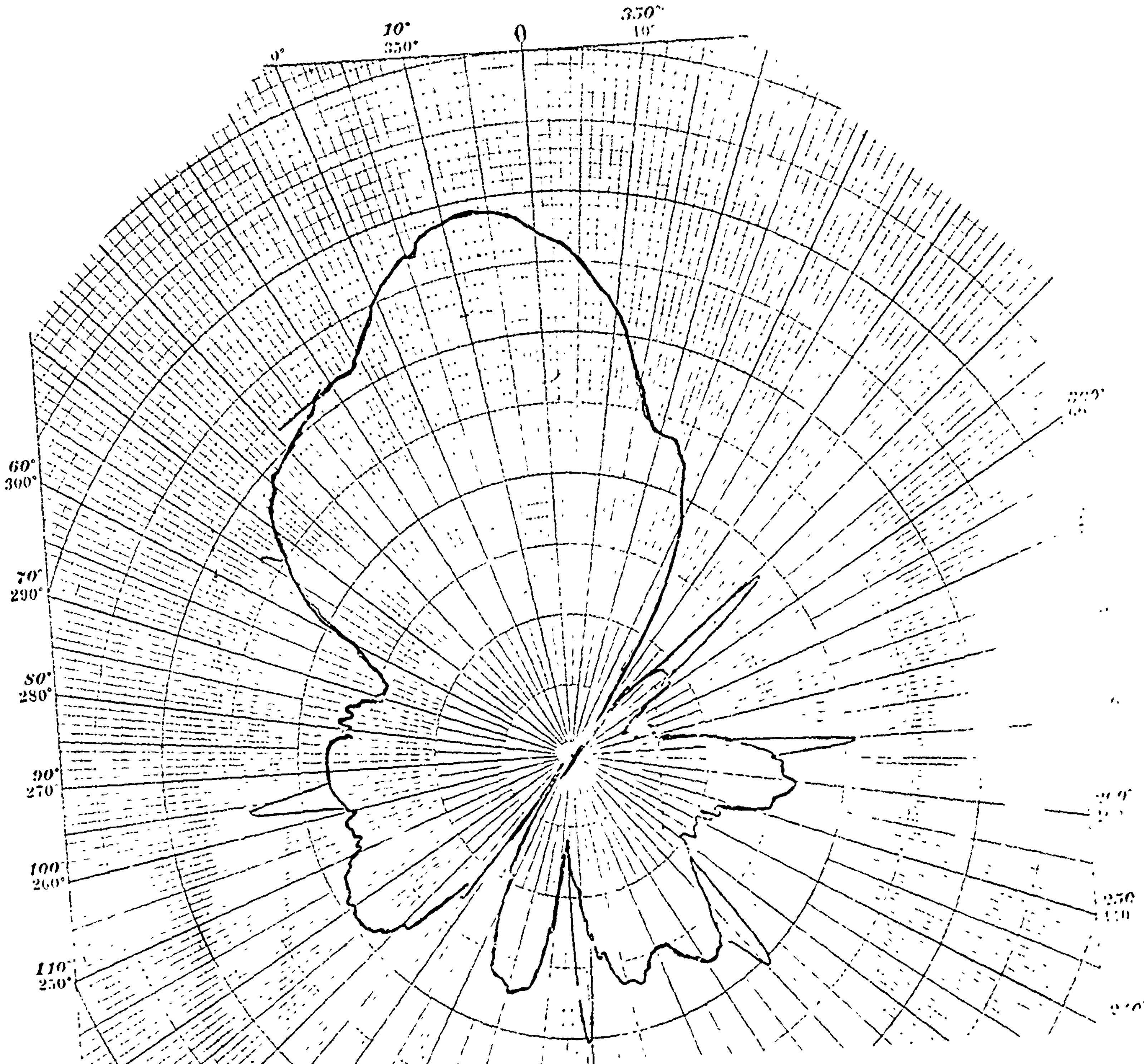


INSTRUMENTATION
Fig. 1 to 954-4-64 dtd 22 Jan 1964



T E S T   G E O M E T R Y

Fig 2 to 954-4-64 dtd 22 Jan 1964



TRANSMITTING DIRECTIVITY PATTERN

TRANSDUCER SOURCE PROJECTOR

SERIAL ______ AXIS Z FREQ. 5.0 kc

TEST DISTANCE 23' DEPTH 17' SIGNAL ______

PROJECTOR ______ SER. ______ OPER. ______ DATE ______

FIG. 3 TO 954-4-64 Dtd. 1-22-64

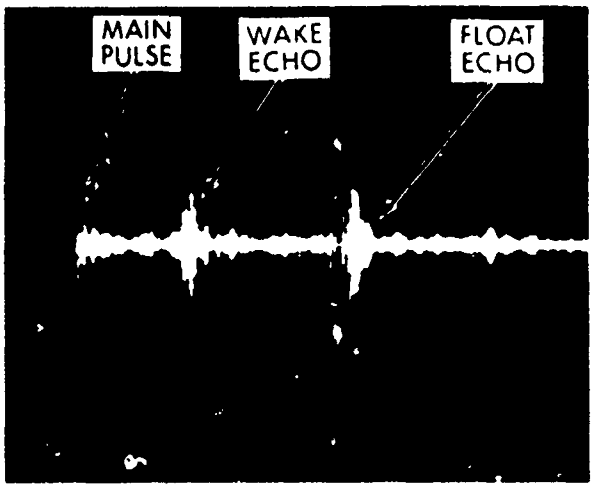


FIG.4

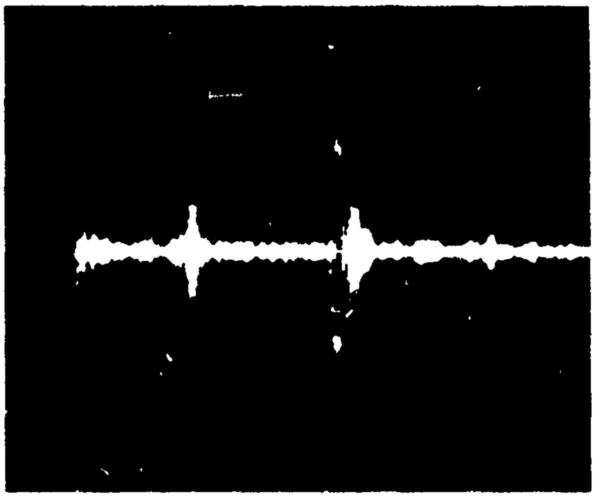


FIG.5

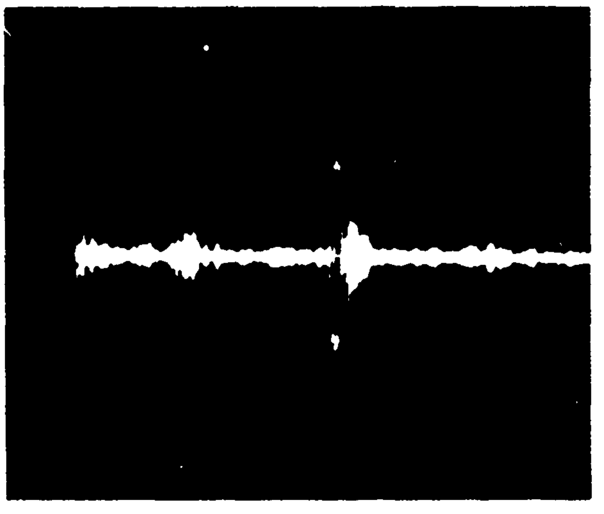


FIG.6
OUTPUT OF 2FT LINE HYDROPHONE
VERTICAL SENSITIVITY 0.5 V/CM
HORIZONTAL SENSITIVITY 10MS/CM

USL Tech Memo No. 954-4-64

U. S Navy Underwater Sound Laboratory
NP24 - 23697 - 1 - 64

Official Photograph

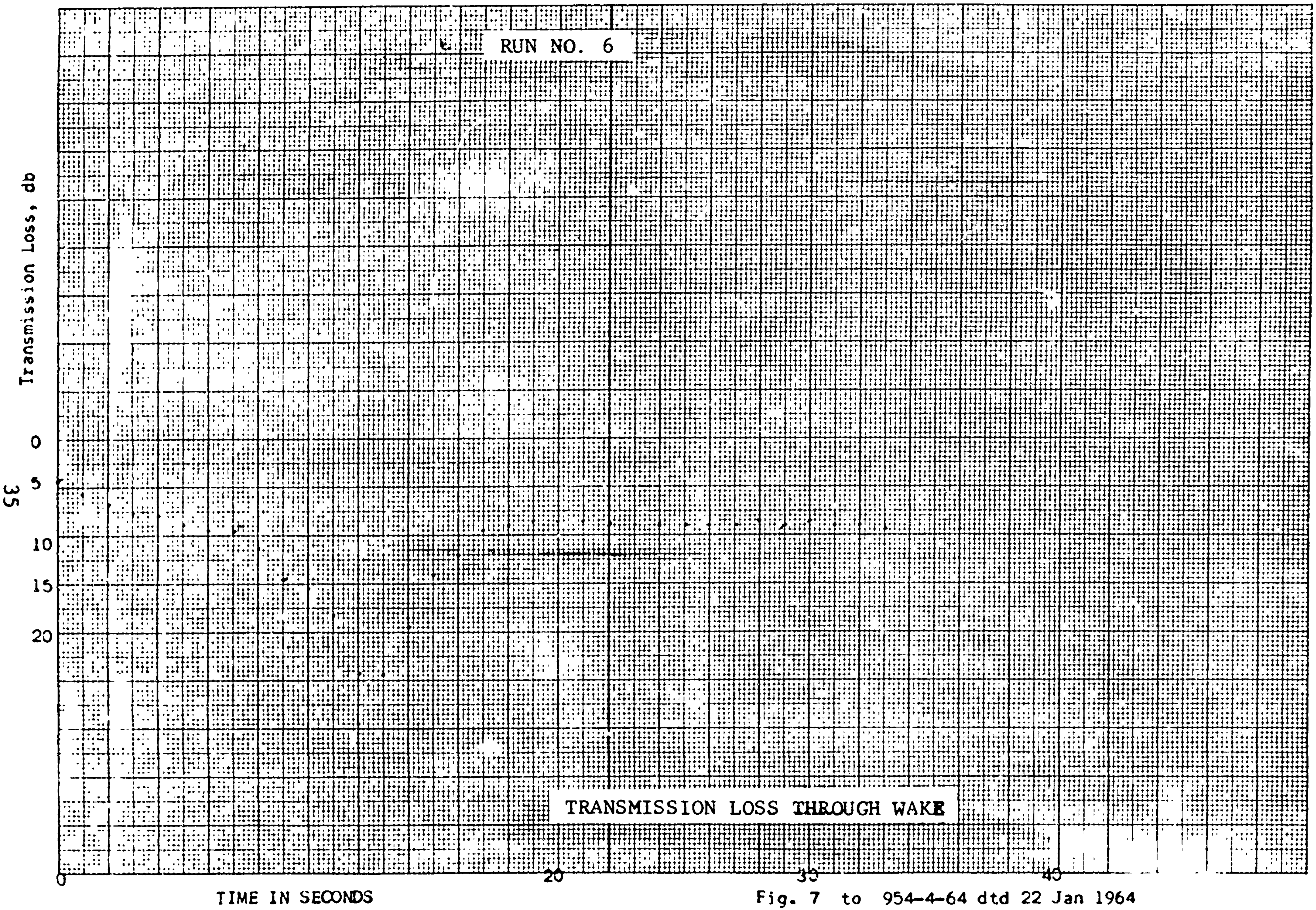


Fig. 7 to 954-4-64 dtd 22 Jan 1964

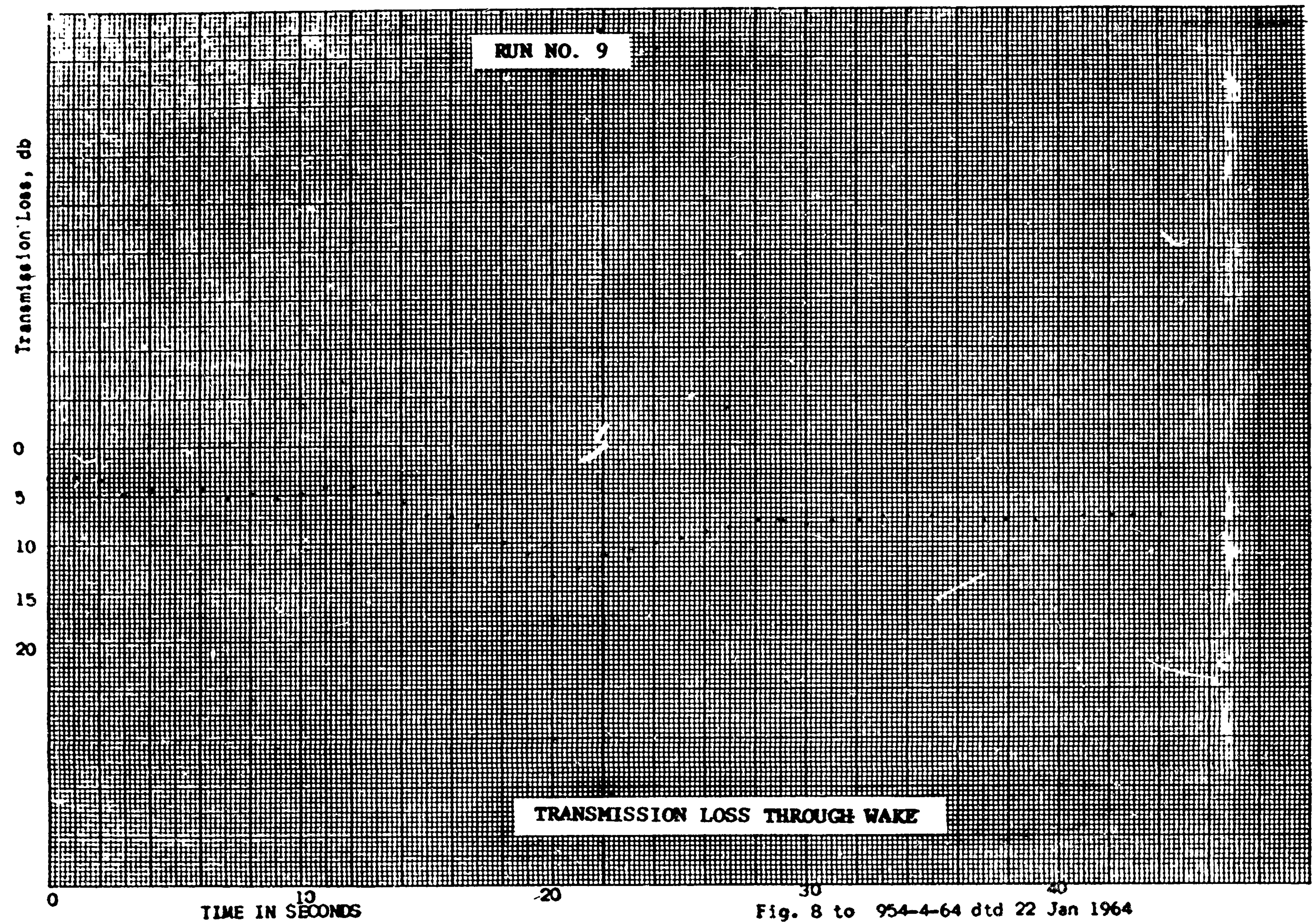


Fig. 8 to 954-4-64 dtd 22 Jan 1964

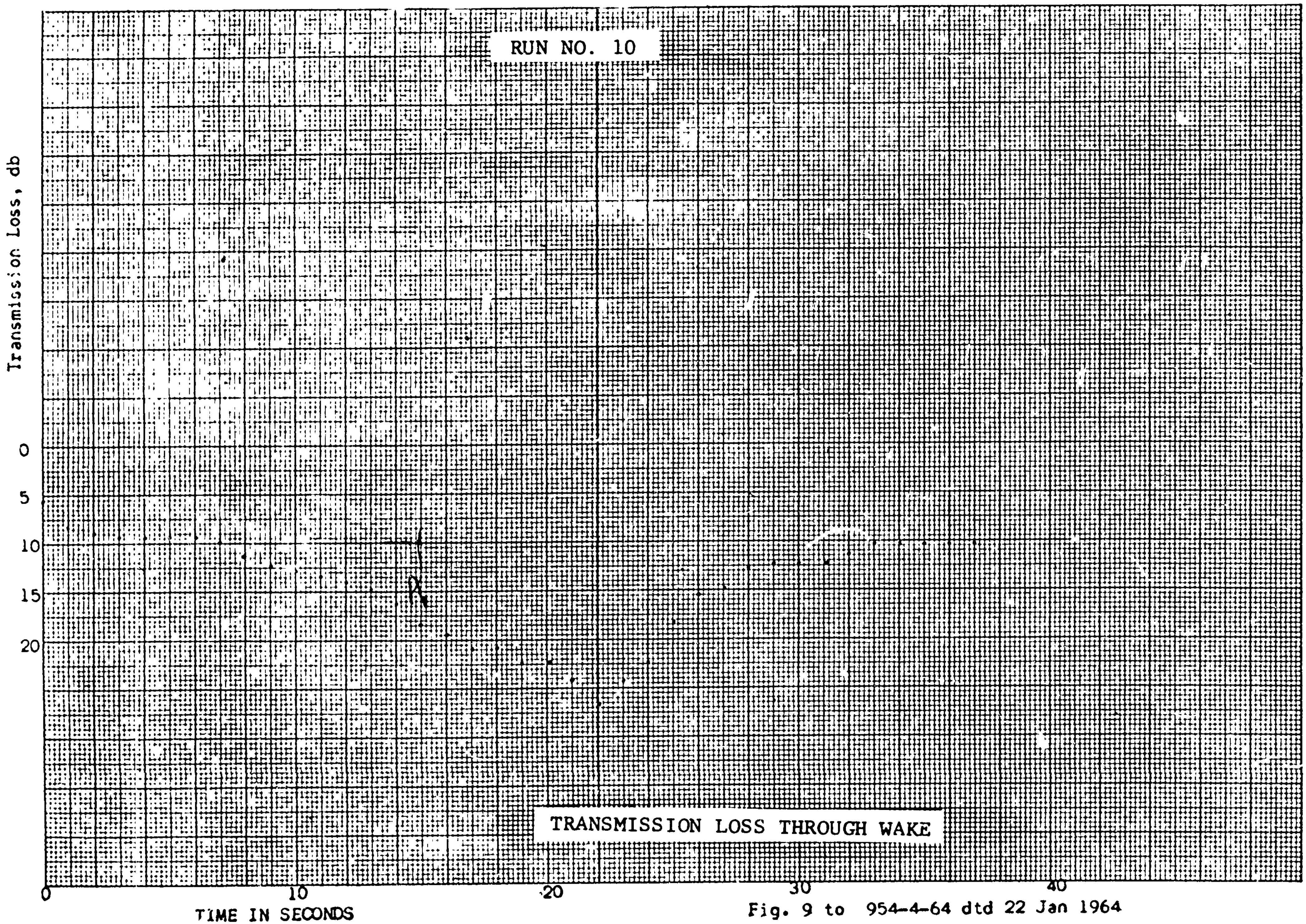


Fig. 9 to 954-4-64 dtd 22 Jan 1964

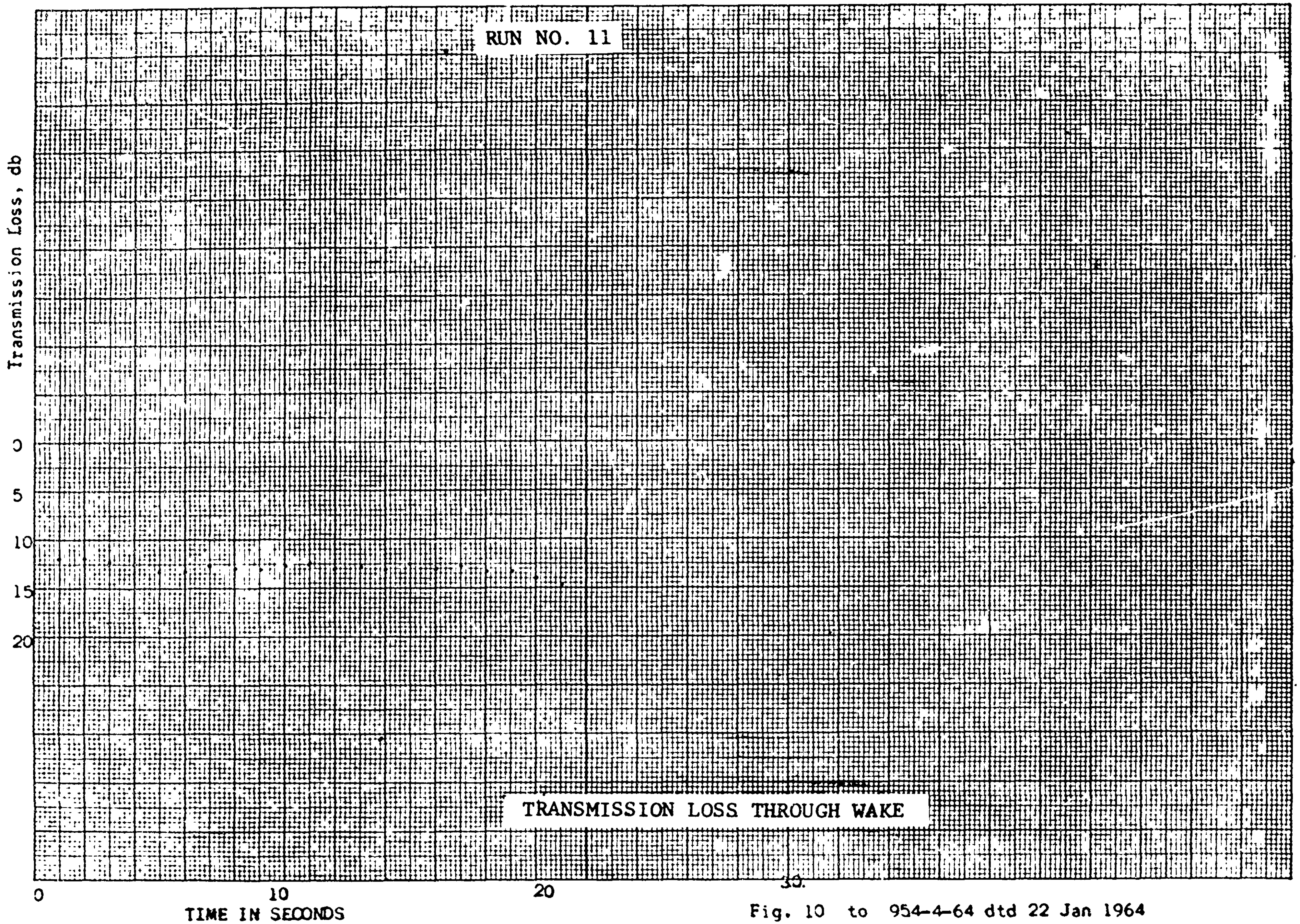


Fig. 10 to 954-4-64 dtd 22 Jan 1964

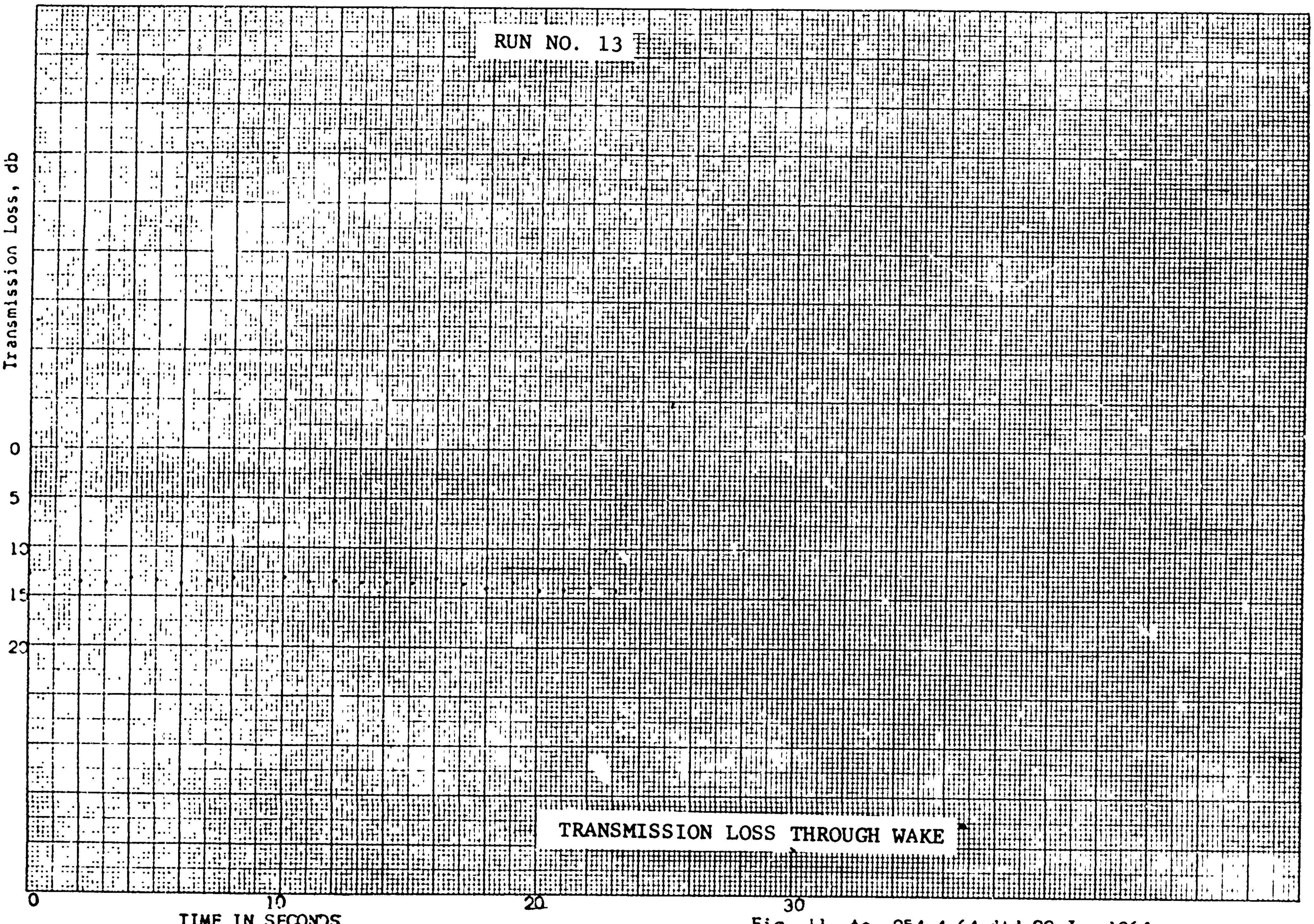


Fig. 11 to 954-4-64 dtd 22 Jan 1964

APPENDIX B

COST ANALYSIS OF CHEMICALS

The replacement cost of one full load, to be used in the experimental model, is $220. The cost is based upon the price of the chemicals in small quantities and experimental manufacturing methods.

The estimated cost for quantities of 15,100 and 500 are given below.

Number of Loadings	Materials	Labor	Total
15	2200	450	2650
100	11,000	1000	12,800
500	48,000	7200	55,200

The above prices include normal overhead, G&A and profit.